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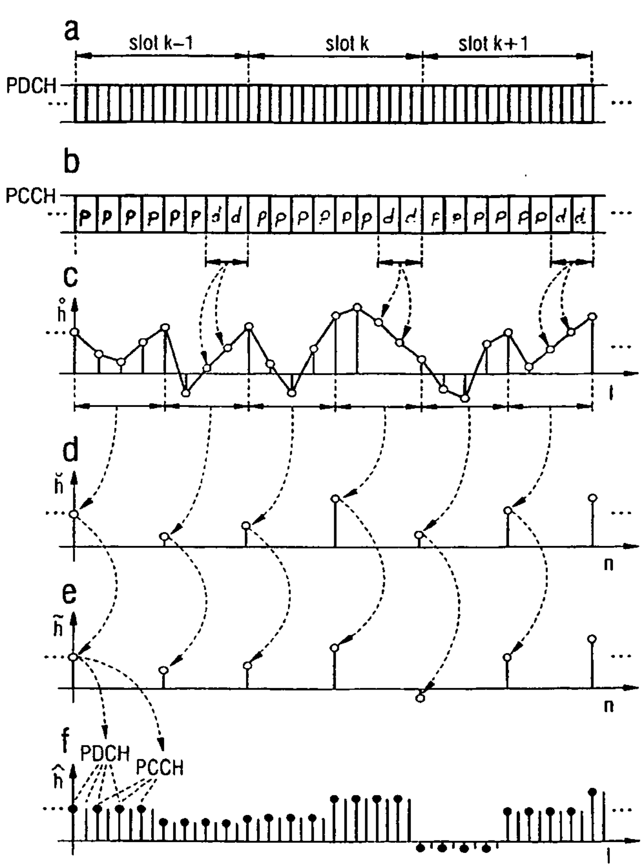
(54) Title: PILOT-ASSISTED CHANNEL ESTIMATION



(57) Abstract: The present invention relates to a method for pilot-assisted channel estimation for code channels comprising pilot symbols interlaced to other data symbols. For improving the adaptation to different channel situations the invention proposes that a received code channel is sampled to form symbol samples, replacing symbol samples relating not to pilot symbol samples by substitute symbols, post-processing the data stream that includes the substitute symbols and adapting the rate of the post-processed data stream. The invention also relates to an adaptive interpolation method for pilot-assisted channel estimation. To improve interpolation the invention further proposes to evaluate the channel situation and switch between at least two different interpolation methods in respect to the channel evaluation results.

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PILOT-ASSISTED CHANNEL ESTIMATION WITH PILOT INTERPOLATION

FIELD OF THE INVENTION

The present invention relates to a method for pilot-assisted channel estimation. The invention also relates to an adaptive interpolation method for pilot-assisted channel estimation. The invention relates also to receivers devices, e.g. for mobile communication.

BACKGROUND OF THE INVENTION

In CDMA communication systems, known pilot symbols are commonly interlaced with unknown user data or control symbols to enable estimation of complex amplitude weights of fading propagation paths in the receiver. Regardless whether a common pilot channel (CPICH) is available or not, amplitude weights (channel estimates) are necessary for RAKE receivers employing maximum ratio combining (MRC). Furthermore, channel estimates are often used for signal power and interference measurements. Hence, they support the determination of signal-to-noise ratios (SIR) or signal-to-interference ratios and thus have a direct impact on the quality of power control mechanisms essential for mobile communication systems based on CDMA techniques. In addition, channel estimation can be the common base for Doppler frequency estimation, generally performed over longer lime intervals, e.g. over multiple frame periods.

The channel estimates needed for each finger of a RAKE receiver are characterized through fading, resulting from fluctuation due to Doppler shifts originating from the relative movement between transmitter and receiver, and are disturbed by the effective signal-to-noise ratio (SNR) or signal-to-interference ratio (SIR).

Conventional very low-complexity channel estimation methods employ a slot-based approach, which applies any post-processing of the initial (re-modulated) pilot-symbols on the average over all pilot-symbols available in a slot. In order to further reduce noise effects an additional sliding averaging over two or more slots is often used.

The disadvantage of conventional slot-based channel estimation schemes is that they do not account for a wide range of different channel fading situations, i.e. very low and very high mobile speeds (or equivalently Doppler), so that their performance is not optimal with respect to the estimation error. Especially, for very high Doppler frequencies (e.g. > 200km/h) the slot-based approaches incorporate a sampling rate of the channel estimates that is too low to be able to follow the fading of the propagation path.

For the time instances of the unknown user data or control symbols the channel estimates have to be interpolated. Conventional low complexity interpolation methods simply apply sample & hold or linear interpolation between respective instances of known pilot symbols using rectangular coordinates (real and imaginary parts).

SUMMARY OF THE INVENTION

It is an object of the invention to provide a method and an apparatus respectively that can cope with a wide range of different channel fading situations.

This object is achieved by replacing samples relating not to pilot symbols by substitute symbols that have been interpolated from the samples of the pilot symbols. .In preferred embodiments the resulting data stream is post-processed and/or a rate adaptation is applied. Optionally after replacement of unknown symbols with substitute symbols symbol averaging may be performed.

The proposed improved channel estimation method allows choosing the sampling rate of the post-processing device for the channel estimates in a flexible way, depending on changing channel conditions, i.e. with respect to the current Doppler. Thus the sampling rate may be chosen such that the samples relate to symbols.

Preferably initial channel estimates originating from pilot-symbols that are usually modulated with a known symbol sequence are used. The principal procedure, further denoted as symbol-based channel estimation approach, can be described as follows: First, after re-modulation with the known pilot symbols, unknown symbols are replaced by either using an appropriate interpolation method or by iterative replacement through a feedback of tentative decisions from RAKE or decoder output. Afterwards, further post-processing aims at a reduction of noise and interference effects. For this, symbol estimates can optionally be averaged in order to be able to reduce the sampling rate of the subsequent signal processing operations. Then, the post-processed output is interpolated to adapt to the symbol rates required for Maximum Ratio Combining in the RAKE. E.g. this are the symbol-rates of the PDCH (I branch) and PCCH (Q branch) signals.

For the post-processing a non-causal forward-backward filter either implemented as multiplication method or addition method is preferably used in order to combat non-linear phase distortions normally inherent in other filter types.

The benefit of the invention is that it provides low complexity and improved overall reception performance through better channel estimates. Further benefits are no non-linear phase distortions by the filters. The ability to cope with a wide range of Doppler frequencies or mobile velocities includes very high speeds (e.g. up-to 500km/h). Adaptive adjustment of cut-off and center frequencies of the post-filters combined with optional averaging of initial channel estimates. The invention allows flexible sampling rate reduction in post-processing units according to desired needs. A trade-off between power consumption and performance is possible. Doppler estimation as well as power and interference

measurements can inherently be improved and can thus improve power control mechanisms. Filter design can be done in time- or frequency domain. For the replacement of unknown symbols optional iterative feedback structure possible that exploits tentative decisions from RAKE or decoder output. The invention is applicable to all physical layer transmission formats that contain pilot symbols, whether or not interlaced with data and/or control symbols.

Another aspect of the invention is that known interpolation schemes do not account for different channel fading situations, i.e. different mobile speeds, so that their performance is not optimal with respect to the estimation error. The preferred channel estimation method employs interpolation of the polar coordinates (amplitude and phase) between known pilot symbols combined with a fallback mode to linear interpolation of real and imaginary parts (rectangular interpolation). The latter should account for very small changes in amplitudes, or phase shifts of multiples of around 360 degree and is established by a respective threshold setting adapted to the actual channel situation. Performance figures show potential improvements compared to other known interpolation methods with similar low complexity.

By the adaptation of the used interpolation method interpolation for fading channels is improved as well channel estimation performance. This method stands out for low complexity.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following the invention will be further described according to the figures and by means of examples.

Fig. 1 Slot structure of pilot channel with known pilot symbols and unknown data symbols

Fig. 2 Typical example of a receiver structure for UTRA PRACH

Fig. 3 Conventional slot-based channel estimation approach applied to UTRA PRACH

Fig. 4 Symbol-based channel estimation approach applied to UTRA PRACH

Fig. 5a Forward-backward filter realizations with multiplication method

Fig. 5b Forward-backward filter realizations with addition method (AM)

Fig. 6 Time-domain realization example of a 1st-order exponential filter

Fig. 7 Principles of different interpolation methods

Fig. 8 Performance comparison of conventional slot-based and symbol-based channel estimation according to the invention

Fig. 9 Frequency spectrum of 1st-order exponential filter for $\lambda = 0.8$

EMBODIMENT OF THE INVENTION

For describing the invention a third- generation wideband CDMA (3G WCDMA) system specified by the Third Generation Partnership Project (3GPP) for IMT-2000/UMTS has been chosen as an embodiment. This system is well specified by various Technical Specifications and so well-known to the person skilled in the art thus for sake of conciseness the only parts of this well-known system are described that are linked directly with the invention.

According to the technical Specifications of a WDCMA system the physical random access channel (PRACH) is used for initial access as well as for low-volume user data transmission. Low access delay and high throughput are required when transmitting short messages on the contention-based PRACH from the user equipment (UE) to the base station via the so-called uplink. In WCDMA a PRACH consists of repeated and power ramped preambles followed by a message part. Transmission on the message part is triggered by reception of an acquisition indicator on the acquisition indicator channel (AICH). Since neither AICH detection nor power ramping of the preamble influence the principal behavior of the channel estimation of the message part, AICH detection is not considered here.

A orthogonal modulation where in-phase and quadrature component may carry different data is used in the uplink. Thus in uplink two physical channels are formed, on by the symbols transmitted on the In-phase component and the other by the symbols transmitted on the quadrature component. The message part has the same structure as a uplink dedicated physical channels (UL-DPCH) and is transmitted in the in-phase component. Hence this channel on the in-phase component is referred to as physical data channel (PDCH). The channel formed by pilot symbols multiplexed with other control information on the quadrature branch is called physical control channel (PCCH). This should not be seen as a restriction of the invention as in the downlink the pilot symbols are modulated as a complex signal to which the invention may be applied in the same way.

Fig. 1 depicts the frame structure of the physical control channel PCCH. as stream of data symbols 1. A certain number of data symbols build up a frame, whereby a frame is transmitted in a time slots 4. A frame contains known pilot symbols 2 (p[l]) and unknown control symbols 3 (d[l]), where $l = \kappa \cdot N_S + \tau$ denotes the consecutive symbol index belonging to slot κ and slot-based index τ.

Figure 2 depicts a typical receiver structure employing channel estimation for a set of N_R RAKE fingers for the application example of the UMTS Terrestrial Radio Access (UTRA) Physical Random Access Channel(PRACH). After selection of a receive band (not shown as not part of the invention) the receive signal is sampled into a in-phase samples I and quadrature samples Q. As in a WCDMA system the transmitted signal is filtered with a root raised cosine filter in order to reduce neighbor band emissions the samples I,Q are fed to a pulse matched filter 5 for undoing this type of "pre-distortion". The filtered samples are then processed by a preamble detector 7 which determines the individual delays of the different identified paths. In a variable delay buffer 6 the R samples are generated of each sample, whereby each sample is delayed according to delays which have been determined by the preamble decoder 7. Hereby a number R of so-called RAKE fingers is generated which are descrambled and despread by de-scrambling and de-spreading means 8. A tap weight estimator 13 estimates the channel properties of each identified RAKE finger. In a maximum ratio combiner (MRC) 10 the RAKE fingers are coherently combined. Hereto the complex conjugates of the path weight estimates determined by the tap weight estimator 13 are first multiplied with the corresponding descrambled and despread samples by means of multipliers 11. The output samples of the multipliers 11 are then summed up by a adder 12 of the MRC 10. Further delay means 9 may be inserted between the descrambling and despreading unit 8 and the MRC unit 10 to compensate processing delay of the tap weight estimator 13. The output signals PDCH, PCCH of the MRC unit 10 is then fed to a decoder for further processing (not shown).

The problem addressed by the invention is how the tap weight estimator 13 may be optimized for a slot-based estimation of channels.

Figure 3 shows the conventional prior art slot-based approach and the required post-processing steps for the UTRA PRACH frame format. Fig. 3a shows the physical data channel PDCH which is transmitted by the in-phase component of the transmit signal. Fig. 3b shows correspondingly the physical control channel PCCH which is transmitted by the quadrature component of the transmit signal. As the PCCH is always transmitted with the lowest possible transmission rate the symbols of the PCCH are always longer or at least equal to the symbols of the PDCH. In the WCDMA system the first part of a slot k consists of pilot symbols p and the last part of each slot consists of control symbols d. As the content of the control symbol is a priori not known an estimation can be based only on the a priori known pilot symbols. On basis of the pilot signals of each slot a mean channel response $\dot{h}$ is calculated as an average for each slot (Fig. 3d). That helps to keep the sampling rate of succeeding operations low. The common approach for noise supression, quite often used due to complexity reasons, applies sliding window averaging over two succeeding slots, so-called 2-slot averaging. Fig 3d shows the hereby obtained noise filtered channel responses $\breve{h}$. After removal of unknown symbols a re-modulation with the inverse pilot symbols takes place. In the PCCH case considered here, re-modulation with the a priori known pilot symbols = -j is equal to a phase rotation by -π/2. In order to reduce noise and interference effects, the post processing of the re-modulated symbols is performed in two steps. First, as shown in Fig. 3e initial estimates $\tilde{h}$ are obtained for each slot. Then, shown in Fig. 3f the initial estimates $\tilde{h}$ are further averaged or post-filtered to averaged estimates $\hat{h}$. For rate adaptation to different symbol rates of PDCH and PCCH, the post-processed output has to be interpolated afterwards.

It must be noted that the depicted preamble detector should be used for path delay estimation in all cases in which a preamble is transmitted, e.g. for discontinuous physical channels like PRACH and Physical Common Packet Channel (PCPCH). The preamble detector has to be replaced by a searcher and

tracker unit in case of continuously transmitted dedicated physical channels like e.g. UL-DPCH, or during the message part transmission of PCPCH as well.

In Fig. 4 the embodiment of the invention is shown where the initial estimates are based on symbol basis. The PDCH and PCCH depicted in Fig. 4a and 4b respectively correspond to Fig. 3a and 3b. For the samples of the a priori known pilot symbols an estimate $\dot{h}$ for each pilot symbol can be calculated. As the data symbols d are a priory not known appropriate substitute estimates have to be taken. In simulations it has turned out that a linear interpolation for the data symbols from the last pilot symbol of a slot k and the first pilot symbol of the succeeding slot k+1 will give sufficient performance.

In a first interpolation step, after re-modulation with the known pilot symbols all unknown data symbols are replaced by interpolated values. As the simplest solution a linear interpolation of the last known pilot symbol of a slot κ and the first known pilot symbol of the succeeding slot $\kappa+1$ will already show better performance than the conventional slot-based solution described in Fig. 3. In a next step the symbols may be averaged prior to filtering them in a post-processing step in order to reduce noise and interference effects. At last in a second interpolation step a rate adaptation is applied.

For the post processing process preferably a non-causal forward-backward filter is used in order to combat non-linear phase distortions usually inherent to other filter types. The non-causal forward-backward filter may be implemented either as multiplication method or addition method. Fig. 5 depicts possible realizations of the two filter types using an underlying causal base filter described by its impulse response

$$g_C[n] = \mathrm{IDTF}\{G_C[\nu]\}.$$

Fig. 5a depicts an implementation of that post-processing filter as an FBMM filter using a first discrete filter 14, followed by a first sequence reverser 15. A

second discrete filter 16, having the same filter properties as the first discrete filter 14 filters the reversed sequence. The filtered reversed sequence is reversed again by a second sequence reverser 17. In another embodiment the post-processing filter is implemented as a FBAM filtered. This filter as shown in Fig. 5b has a parallel structure. The channel responses $\breve{h}$ are filtered in a first filter branch by a first discrete filter 18. In a parallel filter branch the channel responses $\breve{h}$ are first fed to a first sequence reverser 19, filter afterwards by a second discrete filter 20 and reversed again by a second sequence reverser 21. The results of the first filter branch 18 and the second filter branch 19, 20, 21 are then summed by an adder 22 and then multiplied by a factor of ½.

As an alternative hereto Figure 6 shows a possible time-domain realisation example of a causal base filter given by the discrete Fourier transform of a 1st-order exponential filter

$$G_C[\nu] = G_E[\nu] = \frac{1-\lambda}{1-\lambda e^{-j2\pi(\nu-\nu_0)/N}}$$

where λ is the filter coefficient, N is the DFT length, and ν_0 denotes the discrete center frequency of the filter. Applying the exponential filter $G_E[\nu]$ to the initially unfiltered channel estimates $\tilde{h}$ $[m_i,n]$ results in the difference equation

$$\tilde{h}[\dot{m}_i,n] = (1-\lambda)\tilde{h}[\dot{m}_i,n] + \lambda\tilde{h}[\dot{m}_i,n-1]$$

where m_i denotes the delay assigned to the i'th RAKE finger, and n is the sampling instant. The cut-off frequencies of the filters should be chosen such that they adapt to an estimated Doppler frequency measured in the receiver and the respective sampling rate of the post-processing entities of the pilot-symbols.

In general, interpolation is done by an appropriate insertion of N_{ip} symbols between two known pilot symbols. Let $v[l_1]$ and $v[l_2]$ represent two known symbols between which an interpolation should take place. Hence, the indexes l_1

and l_2 depend on whether a replacement of the unknown symbols d[l](1st interpolation step) or a rate adaptation of all symbol instances (2nd interpolation step) is considered. They shall refer to sampling instances of the respective interpolated signal, which is represented by w[l] further.

Several interpolation methods may be used. In all cases, interpolation is done by an appropriate insertion of symbols between two known symbols. Let $v[l_1]$ and $v[l_2]$ represent either channel estimates corresponding to known pilot symbols of the received signal in case of symbol replacement, or values of the post-filter output signal in case of rate adaptation. Hence, the indexes l_1, l_2 depend on whether unknown symbol replacement or rate adaptation is required. They refer to sampling instants of the respective interpolated signals, which shall be represented by w[l] further on.

Fig. 7 schematically shows conventional interpolation methods for $l = l_1 \ldots (l_2 - 1)$ that may be used for the above described channel estimation:

a) Sample & hold interpolation keeps the signal value constant over all N_{ip} samples in the interpolation interval

$$w[l] = [l_1]$$

b) Linear (rectangular) interpolation applies interpolation on real and imaginary part:

$$w[l] = v[l_1] + (l - l_1) \cdot \frac{v[l_2] - v[l_1]}{N_{ip}}$$

c) Linear phase interpolation uses the differential phase estimate

$$\Delta\varphi = arc\{v * [l1] \cdot v[l_2]\}$$

in order to calculate the interpolated signal. It is assumed that the differential phase estimate Δφ does not exceed a phase rotation of π.

$$w[l] = \frac{\left(v[l_1] + v[l_2] \cdot e^{-j\Delta\varphi}\right)}{2} \cdot e^{j\Delta\varphi \cdot (l-l_1)/N_{ip}}$$

d) Linear polar interpolation employs the differential phase estimate Δφ as well as the differential amplitude estimate

$$\Delta v = \left|v[l_1]\right| - \left|v[l_2] \cdot e^{-j\Delta\varphi}\right|$$

leading to the interpolated signal

$$w[l] = \left(\left|v[l1]\right| + (l - l_1) \cdot \frac{\Delta v}{N_{ip}} \right) \cdot e^{j(arc\{v[l_1]\}-(l-l_1)\Delta\varphi / Nip)}$$

The disadvantage of the above described interpolation schemes is that they do not account for different channel fading situations, i.e. different mobile speeds, so that their performance is not optimal with respect to the estimation error. All interpolation methods mentioned above suffer from the fact that they are not adapted to the underlying fading process of the transmission channel.

In order to combat this, the preferred interpolation method uses linear phase or polar interpolation and provides a fallback mode to linear interpolation in case the following conditions are true:

$$\Delta\varphi \bmod (2\pi) \leq \varepsilon_\varphi$$

and

$$|\Delta v| \approx \left|v[l_{1,2}]\right| \leq \varepsilon_v$$

where ε_φ and ε_v are appropriate thresholds for phase and amplitude values, respectively. The threshold setting preferably is adapted to the actual channel condition, e.g. depending on measured and estimated maximum Doppler frequency.

Performance figures shown in Fig 8 shows remarkable improvements compared to other known channel estimation methods with similar low complexity. Performance criterion is the frame error rate (FER) vs. Average signal-to-noise ratio E_b/N_0 per user data bit of the RA message part (PDCH). The performance figures are valid also for UL-DPCH without power control. Comparison of conventional slot-based and symbol-based performance show that symbol-based channel estimation can lead to significant performance improvements being 1 dB for low to medium speed scenarios and up to 10 dB for high speed scenarios (> 200 km/h). The performance differs only marginal for each kind of linear interpolation. Modified polar interpolation could be optimized to slightly outperform the other linear interpolation methods. However, for low-speed scenarios a linear interpolation does not give a better performance than S&H interpolation if a post-filter is already established.

Further simulations showed that although filters with maximum memory complexity, e.g. ideal low-pass or Wiener filters, obtain best performance for continuos data transmission as for UL-DPCH, they give only marginal improvements of about 0.1 – 0.2 dB compared to FBNN filter due to bursty RA transmission. Hence a good filter choice for all investigated PRACH scenarios is the FBMM filter approach employing modified linear polar interpolation. As can be seen from the frequency spectrum depicted in Fig. 9 for an exponential filter, a FBAM filter and a FBMM filter the FBMM filter shows the best magnitude response of all filters and also shows no phase detoriation. Besides the good performance of the FBMM filter, it appears insensitive to Doppler estimation errors up to at least ±50 Hz and can be easily implemented in time or frequency domain.

Furthermore it has be mentioned again that the invention is not restricted to the specific embodiments and examples described in the present invention. That is, on the basis of the teaching contained in the description, various modifications and variations of the invention may be carried out. A person skilled in the art will readily appreciate that the invention may be applied also to other systems than the WCDMA system that has been chosen as exemplary embodiment.

CLAIMS

1. Method for pilot-assisted channel estimation for a code channel comprising pilot symbols(2) interlaced to other data symbols (3) wherein a received code channel is sampled to form symbol samples (I,Q), symbol samples relating not to pilot symbol samples are replaced by substitute symbols that have been interpolated from the samples of the pilot symbols.

2. Method according to claim 1 wherein the data stream that includes the substitute symbols is post-processed.

3. Method according to claim 1 or 2 wherein a rate adaptation is applied on the data stream with the substitute symbols.

4. Method according to claim 1, 2 or 3 for interpolating samples received of a disturbed, particularly fading channel by evaluating the channel situation and switching between at least two different interpolation methods in respect to the channel evaluation result.

5. Method according to one of claims 4 where one of the at least two different interpolation methods is a linear phase interpolation method.

6. Method according to claim 4 where one of the at least two different interpolation methods is a polar phase interpolation method.

7. Method according to claim 4, 5, 6 where the decision to switch to another interpolation method is based on thresholds for phase and/or amplitude values.

8. Method according to claim 5 where linear interpolation is applied in case the following conditions are true:

$$\Delta\varphi \bmod(2\pi) \leq \varepsilon_\varphi$$

and

$$|\Delta\nu| \approx |\nu[l_{1,2}]| \leq \varepsilon_\nu$$

where ε_φ and ε_ν are appropriate thresholds for phase and amplitude values and linear phase or polar interpolation is applied if this condition does not apply.

9. Method according to claim 4 -8 where the threshold setting is adapted to the actual channel condition.

10. Method according to one of claims 1 – 9 wherein the samples are symbol-based.

11. Method according to method 2 wherein for the post-processing a non-causal forward-backward filter is used.

12. Method according to claim 10 wherein the interpolation is carried out on basis of the last known symbol of a slot k and the first known symbol of a succeeding slot k+1.

13. Communication apparatus comprising a channel estimator (13) for receiving a code channel comprising pilot symbols interlaced to other data symbols wherein the channel estimator (13) samples a received code channel to form symbol samples, replaces symbol samples relating not to pilot symbol samples by substitute symbols.

14. Communication apparatus, particularly for mobile communication where the channel situation is evaluated and in dependence of the evaluated situation a interpolation method is chosen out of at least two different interpolation methods.

FIG. 1

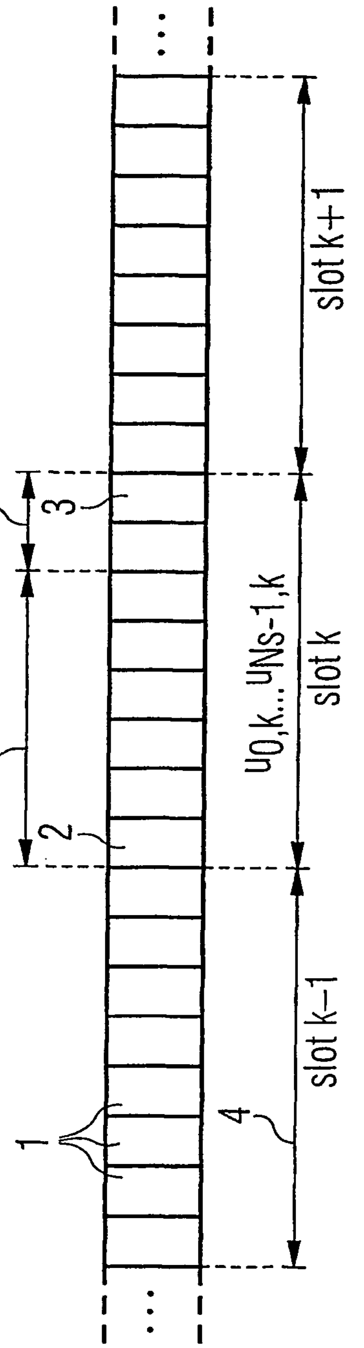
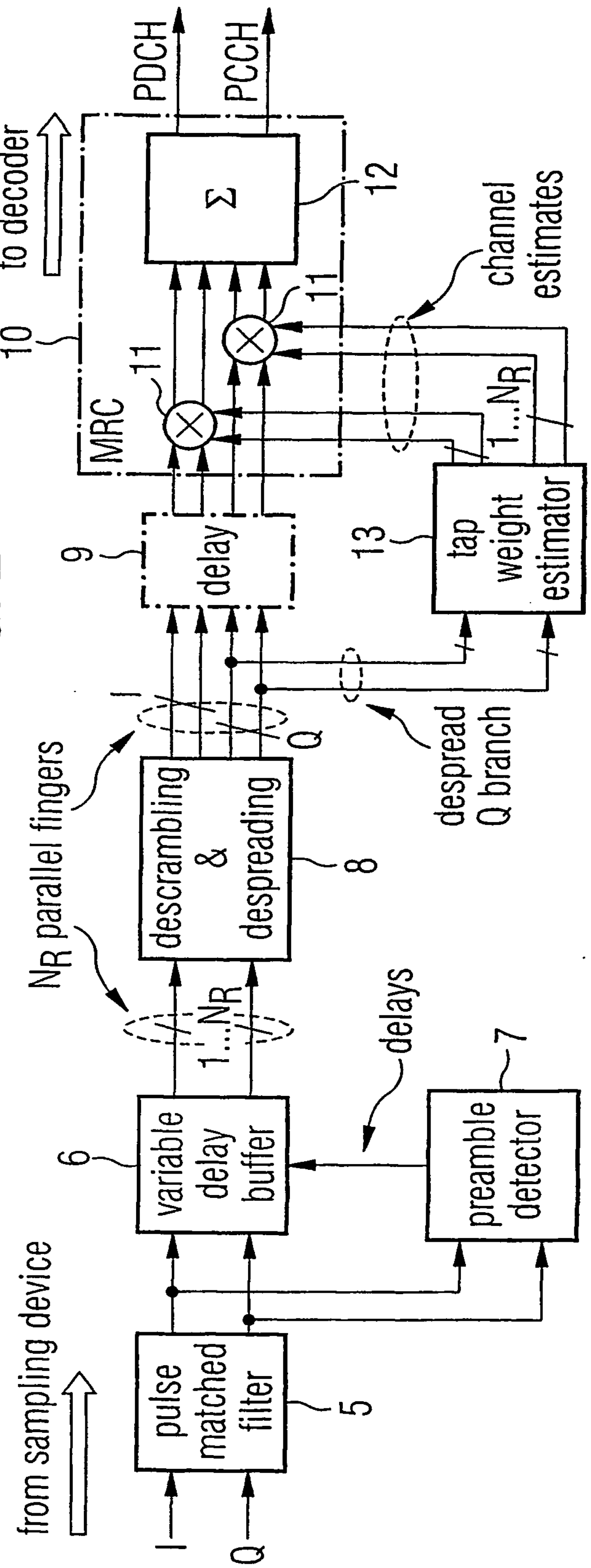

pilot symbols
$p_{0,k} \ldots p_{N_p-1,k}$
control symbols
$d_{0,k} \ldots d_{N_d-1,k}$
$u_{0,k} \ldots u_{N_s-1,k}$
slot k−1
slot k
slot k+1
1
2
3
4

FIG. 2


I
Q
from sampling device
pulse matched filter
5
variable delay buffer
6
preamble detector
7
delays
N_R parallel fingers
$1 \ldots N_R$
descrambling & despreading
8
I
Q
despread Q branch
delay
9
tap weight estimator
13
$1 \ldots N_R$
channel estimates
MRC
10
11
11
Σ
12
to decoder
PDCH
PCCH

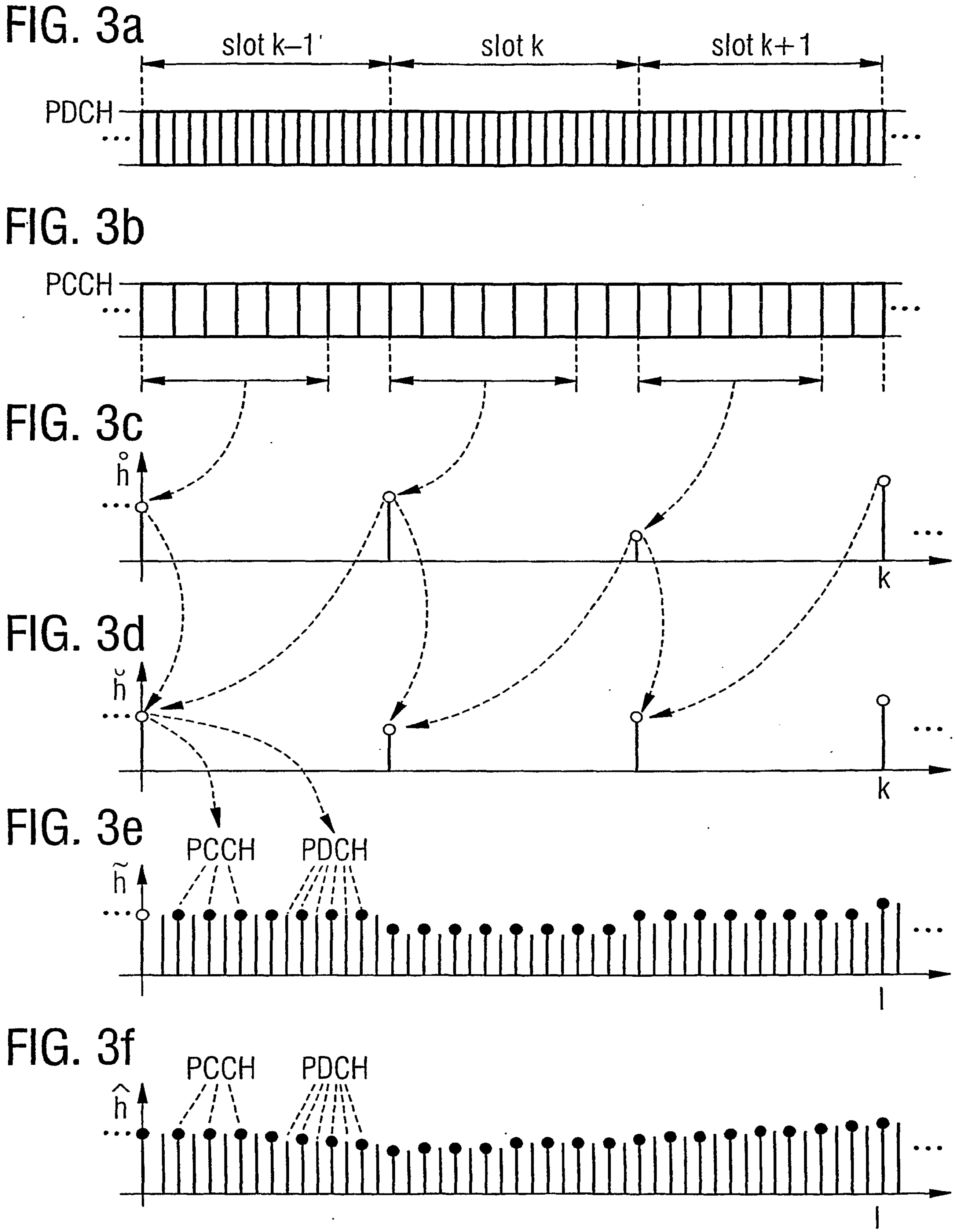


FIG. 3a
slot k−1
slot k
slot k+1
PDCH
FIG. 3b
PCCH
FIG. 3c
k
FIG. 3d
k
FIG. 3e
PCCH
PDCH
l
FIG. 3f
PCCH
PDCH
l

FIG. 4a

FIG. 4b

FIG. 4c

FIG. 4d

FIG. 4e

FIG. 4f

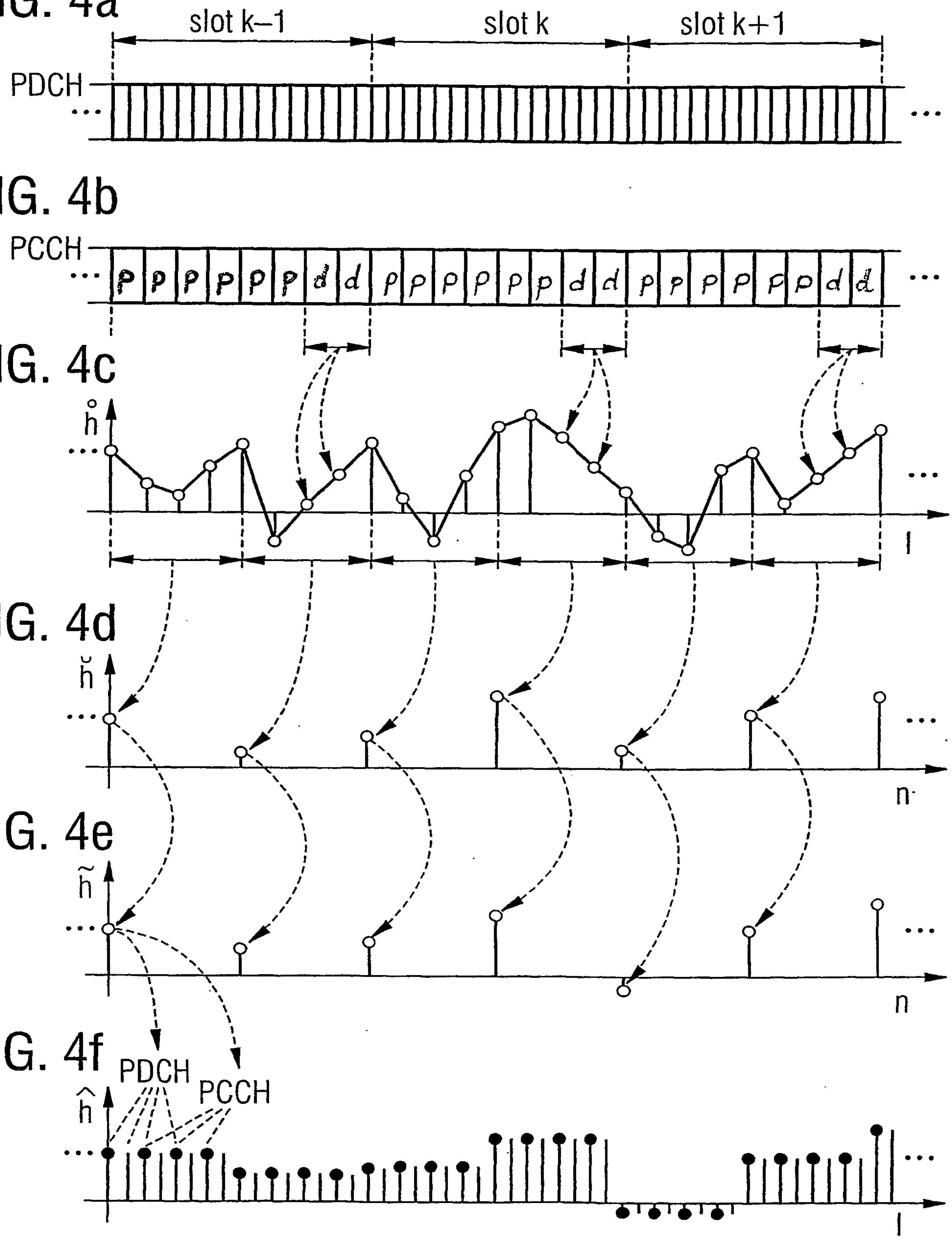


FIG. 5a

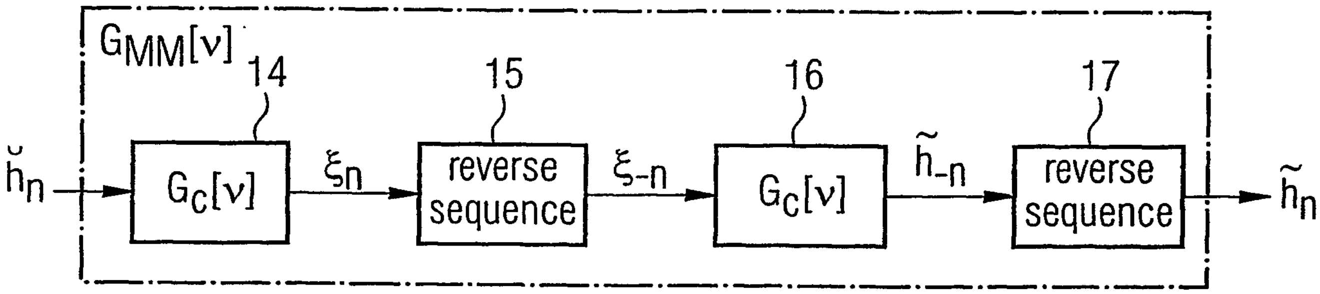


FIG. 5b

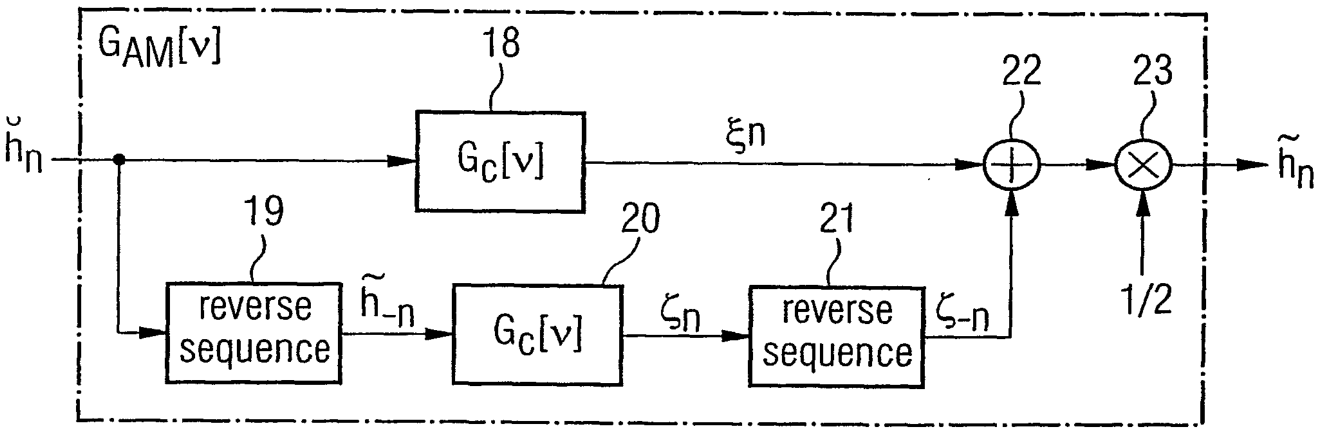


FIG. 6

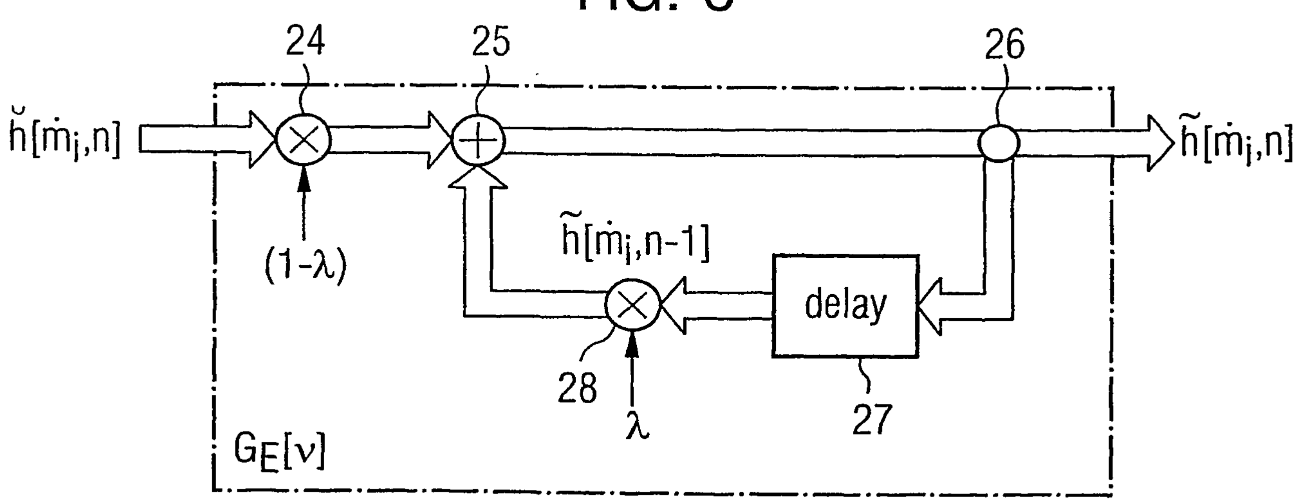
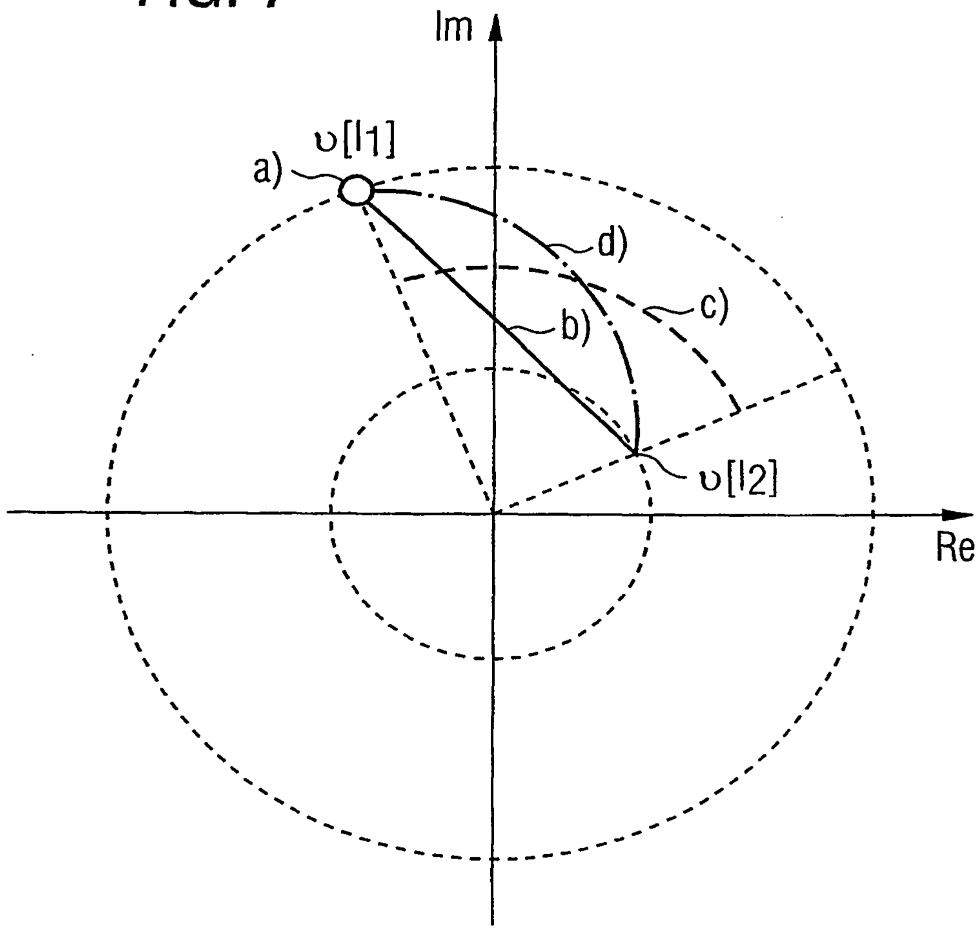
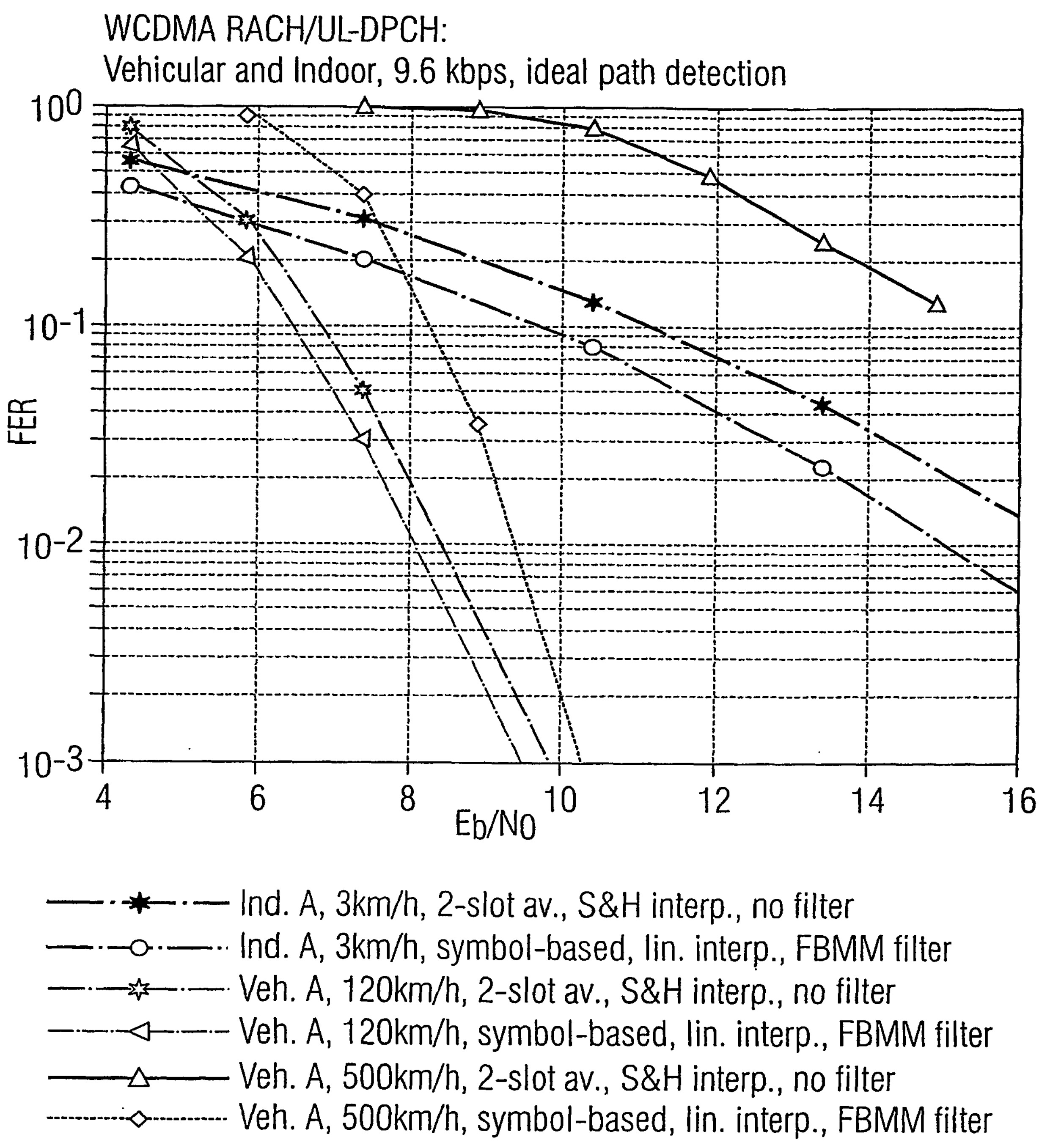


FIG. 7



O a) sample & hold
——— b) linear interpolation
– – – c) linear phase interpolation
–·–·– d) linear polar interpolation

FIG. 8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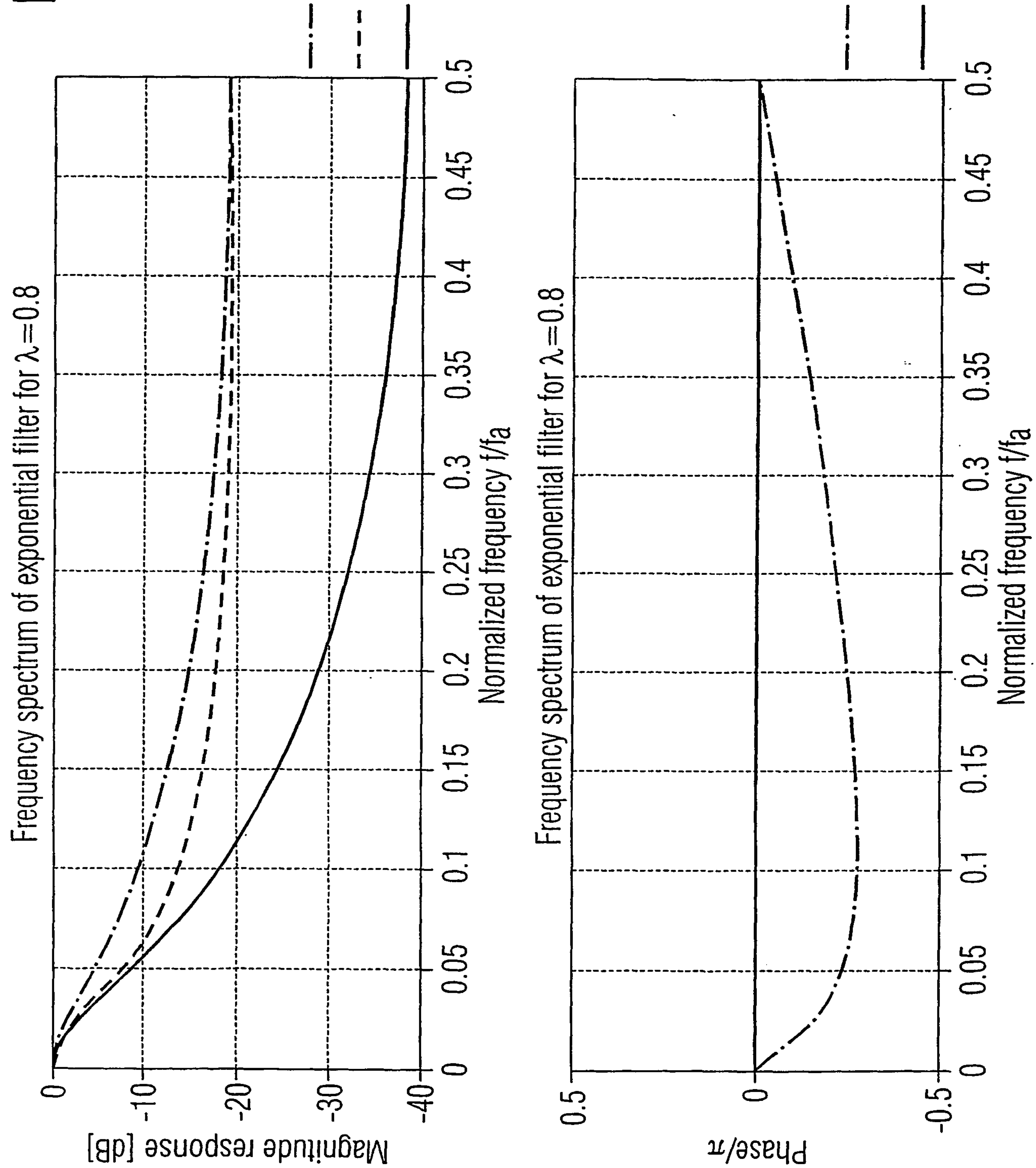
Vehicular and Indoor, 9.6 kbps, ideal path detection
FER
Eb/N0
10^0
10^-1
10^-2
10^-3
4
6
8
10
12
14
16
Ind. A, 3km/h, 2-slot av., S&H interp., no filter
Ind. A, 3km/h, symbol-based, lin. interp., FBMM filter
Veh. A, 120km/h, 2-slot av., S&H interp., no filter
Veh. A, 120km/h, symbol-based, lin. interp., FBMM filter
Veh. A, 500km/h, 2-slot av., S&H interp., no filter
Veh. A, 500km/h, symbol-based, lin. interp., FBMM filter

FIG. 9


Frequency spectrum of exponential filter for λ=0.8
Magnitude response [dB]
0
-10
-20
-30
-40
Normalized frequency f/fa
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
exp. filter
FBAM filter
FBMM filter
Frequency spectrum of exponential filter for λ=0.8
Phase/π
0.5
0
-0.5
Normalized frequency f/fa
exp. filter
FBAM/
FBMM filter

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 01/10680

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L25/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99 60721 A (ERICSSON INC) 25 November 1999 (1999-11-25) page 7, line 1 - line 19 page 11, line 23 -page 12, line 5 ---	1-14
X	DONG XIAOJIAN ET AL: "A novel method of channel estimation for W-CDMA" ASIA-PACIFIC CONFERENCE ON COMMUNICATIONS / OPTOELECTRONICS AND COMMUNICATIONS CONFERENCE. APCC/OECC. PROCEEDINGS. CONFERENCE VITALITY TO THE NEW CENTURY, vol. 1, 18 October 1999 (1999-10-18), pages 582-585, XP002171416 page 583, right-hand column	1-13
A	figure 2 ---	14
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 February 2002	05/03/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Orozco Roura, C

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 715 440 A (NIPPON TELEGRAPH & TELEPHONE) 5 June 1996 (1996-06-05) abstract	1-13
A		14
A	US 5 544 156 A (EWERBRING LARS-MAGNUS ET AL) 6 August 1996 (1996-08-06) column 7, line 15 - line 18	2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 01/10680

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9960721	A	25-11-1999	AU	3869199	A	06-12-1999
			BR	9910500	A	09-01-2001
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EP 0715440	A	05-06-1996	EP	0715440	A1	05-06-1996
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			AU	2422895	A	29-11-1995
			BR	9507529	A	02-09-1997
			CA	2188869	A1	09-11-1995
			CN	1147321	A ,B	09-04-1997
			DE	69524403	D1	17-01-2002
			EP	0758504	A1	19-02-1997
			FI	964344	A	28-10-1996
			JP	10504143	T	14-04-1998
			NZ	285198	A	27-07-1997
			RU	2152686	C1	10-07-2000
			WO	9530289	A2	09-11-1995

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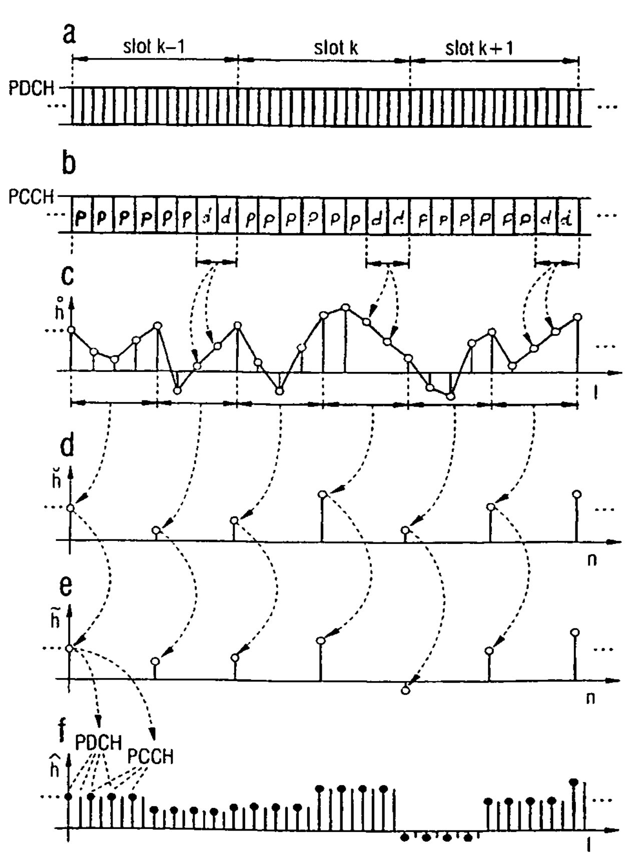
[Continued on next page]

(54) Title: PILOT-ASSISTED CHANNEL ESTIMATION WITH PILOT INTERPOLATION



(57) Abstract: The present invention relates to a method for pilot-assisted channel estimation for code channels comprising pilot symbols interlaced to other data symbols. For improving the adaptation to different channel situations the invention proposes that a received code channel is sampled to form symbol samples, replacing symbol samples relating not to pilot symbol samples by substitute symbols, post-processing the data stream that includes the substitute symbols and adapting the rate of the post-processed data stream. The invention also relates to an adaptive interpolation method for pilot-assisted channel estimation. To improve interpolation the invention further proposes to evaluate the channel situation and switch between at least two different interpolation methods in respect to the channel evaluation results.

WO 02/23840 A1

patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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